

# **Factors Influencing Occurrence, Scale, Mobility, Runout, and Morphology of Mass Movements on the Continental Slope**

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## **LONG-TERM GOALS**

Achieve an improved understanding of the relationships between sedimentation, environment, and the morphology of continental slopes. This goal will be accomplished primarily through investigations within the northern California (Eel River) and New Jersey study areas and incorporation of data from around the World. An underlying assumption of our work is that the occurrence and morphology of mass movement features on the continental slope depend upon a combination of characteristics, each of which varies over the region in a consistent manner. The various components of this project are part of a concerted effort between the geotechnical groups at the USGS and Laval University. Their activities are very much interwoven but, for administrative reasons, annual reports are provided separately.

## **OBJECTIVES**

Identify factors that can be mapped regionally and that determine where and how slope failures occur; derive a basis for producing regional maps that indicate relative landslide susceptibility. Model shear strength development with depth and incorporate this model into continental slope stability, post-failure behavior, and bedform processes. Observe and model pore pressure development in continental slopes. Analyze the relationship between seismic intensity, sediment instability and slope processes. Integrate these elements into geo-hazards assessment.

## **APPROACH**

Our research focuses on the factors that lead to variations in the sedimentological and environmental conditions determining slope failure. We develop improved correlation between engineering classifications and strength factors. We relate compressibility, physico-chemical properties and strength to sediment microstructure, observed using SEM techniques. We simulate sediment accumulation in specially designed large cells. We measure sediment rheological properties in a viscometer. Geotechnical properties are related to sediment density state, obtained from detailed logs of downcore variability of sediment density and sound velocity. Basic strength parameters are obtained using triaxial drained and undrained tests and undrained cyclic tests. Using available bathymetry, and seismic profiles, we develop models tested for stability and mobility. Seismic shaking variations are evaluated probabilistically by seismologists. Pore pressures are either determined *in situ* by means of the Excalibur probe (AGC-Atlantic) or estimated using sedimented rates and consolidation theory. If

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there is charging by bubble-phase gas, or if earthquake shaking disrupts the sediment fabric and causes it to collapse with a resulting increase in the pressure of interstitial fluids. Driving stresses are balanced against strength variations in a geographic Information System (GIS) to obtain a regional estimate of relative slope stability.

Key individuals at Laval are: Jacques Locat, Jean-Marie Konrad, Serge Leroueil, and Priscilla Desgagnés: strength and compressibility measurements, SEM studies, rheology measurements, and simulation of sediment accumulation. At the USGS they are: Homa Lee, Kevin Orzech, Dianne Minasian, and Pete Dartnell: physical property logs of sediment cores and relations between geotechnical and classification properties, algorithms relating sediment properties, environmental factors, and slope stability within the framework of a GIS.

## **WORK COMPLETED**

During FY 01, our research involved mostly one of the two main areas of STRATAFORM: the New Jersey Margin, the Hudson Apron in particular. We continued the laboratory testing and analysis of tests carried out on various cores obtained from the 1999 Marion Dufresne cruise on the New Jersey Margin (Desgagnés *et al.* 2000). Further tests conducted at Laval included five triaxial tests, 10 oedometer tests, 3 SEDCON tests, Atterberg's limits, grain size, mineralogy, microstructure and rheology. A total of 3 long cores were collected (MD992-211, 212, and 213), of which one is kept at Laval. All cores were logged, onboard the ship, at 1-cm resolution for density, sound velocity, and magnetic susceptibility. In addition, core MD992-213 was completely logged with a CATSCAN at a resolution of 1cm. The rheological tests were carried out on mixtures at various water content with a liquidity index from about 1.5 to 4.0. The slope stability analysis of two slides identified on the Hudson Apron were carried out using SLOPE/W. Mobility analyses was carried using BING. Work completed at Laval has been integrated with available data from other projects, mostly ODP related from which strength, water content and density data could be used and compared to our results.

## **RESULTS**

Advanced geotechnical testing of the Hudson Apron sediments indicates that they are normally consolidated, at least in the section investigated (*i.e.* to a depth of 38m). The strength parameters, obtained on reconstituted samples, are defined by a failure envelope with a friction angle of 27° and a cohesion of about 0 kPa (Figure 1). Our analysis of the Hudson Apron area indicates that there are at least two mass movements in the area. They are part a about 100 mass movements mapped by Booth *et al.* (1993). The first one shows a failure plane extending over a distance of about 3 km at a depth of about 50m. It is located near the crest of the slope at a water depth less than 600m. The second one is deeper and extends down to a depth of more than 1000m. Both of these slides took place on a slope of about 4°. Limit equilibrium analyses indicate that the slope is very stable under normal hydrostatic conditions. A high pore pressure is required for the slope to fail. It is speculated that possible source of pore pressure generation could be related to high sedimentation rate or gas hydrates. The implication of either causes is being currently investigated. The rheological properties of the Hudson Apron sediments are quite similar to those of other sediments and follow the general relationship proposed by Locat (1997). The mobility analysis of the Hudson Apron is being investigated using BING. Initial use of the geotechnical characterization of mass movements (Leroueil *et al.* 1996) has been attempted for the New Jersey area (Locat *et al.* 2001a) in the view of providing some insight on regional geo-hazard assessment. This approach enables us to consider all component of the phenomena, from its initiation to the final deposit and by integrating soil or rock mechanics with fluid mechanics. A general framework for submarine landslides risk assessment is shown in Figure 2. Another major component

of the work completed has been the integration of slope stability consideration at a regional scale (Lee *et al.* 2000 and 2001, see also Locat and Lee 2002).

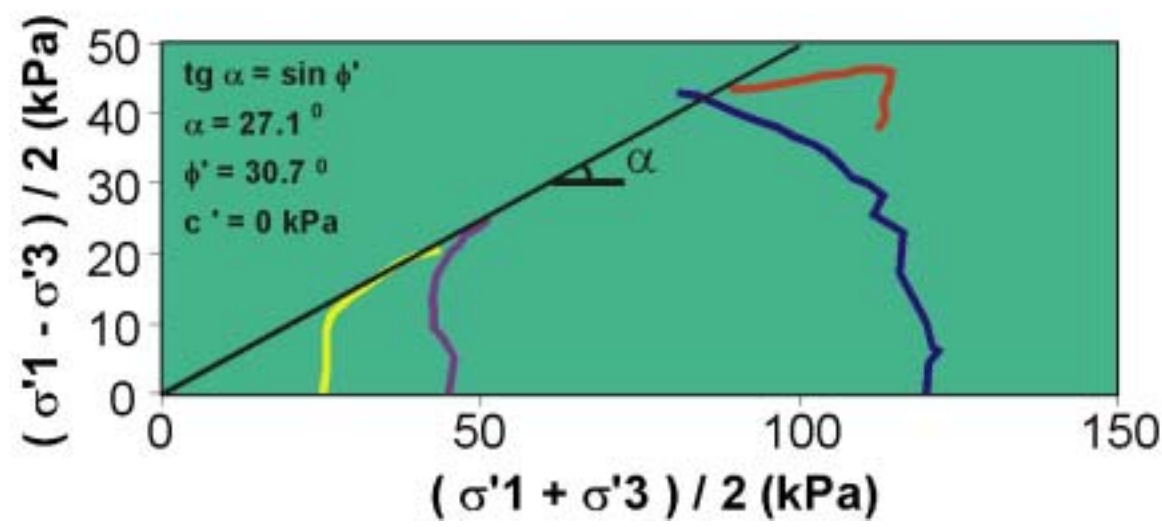


Figure 1. Triaxial tests results showing various stress path grouped around a failure envelope corresponding to a friction angle of 27 and a cohesion of about 0 kPa (Desgagnés *et al.* 2001).

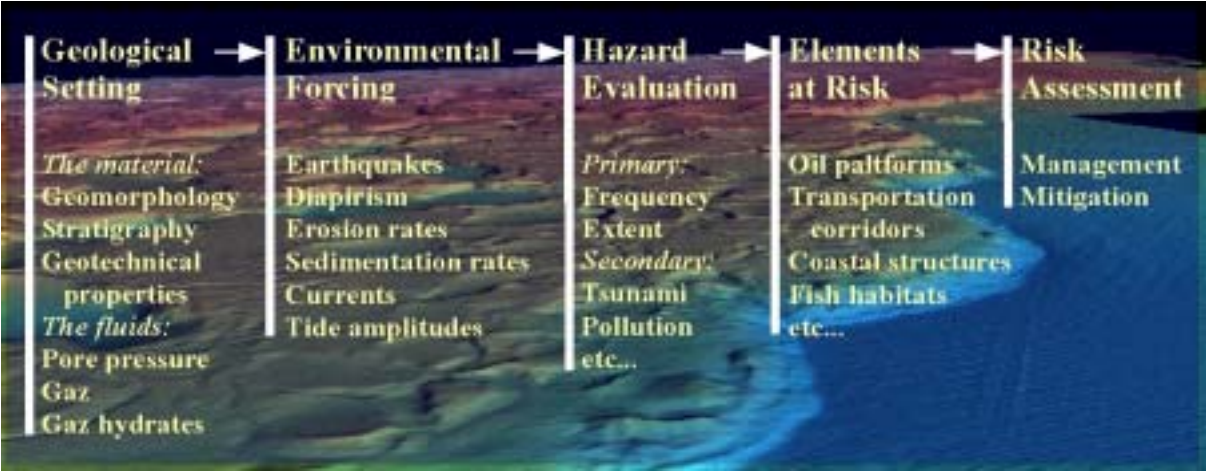


Figure 2. General framework for submarine slide risk assessment (Locat 2001)

### IMPACT/APPLICATION

Relationships developed in this project show the importance of sediment liquidity index and seabed density profiles in representing the behavior of marine sediment. These values can be used to predict regional slope stability and the rheological behavior of debris flows. General strength-density relationships can be used for modeling sediment accumulation and stability (Locat *et al.* 2001b). It is

also now feasible to integrate geomorphological and geotechnical data into a regional analysis of submarine landslide risk assessment.

## TRANSITIONS

Geoacoustic properties are being used by mappers and acousticians to identify lithologies acoustically. Rheological properties are being used by modelers to represent debris flows (Imran *et al.* 2001). Landslide generation models are being used by landscape evolution modelers. Offshore research groups interested in margin (January 1999 Paris Workshop, see Locat 2001) and in oil and energy development were used as a platform to present our knowledge on submarine slope stability and hazard acquired as part of STRATAFORM. A major opportunity was also provided in June 2000 when we were invited to give a keynote lecture on submarine mass movements at the 8<sup>th</sup> International Symposium on Landslides in Cardiff (Locat and Lee 2002). Our knowledge on submarine mass movement, developed as part of STRATAFORM, has been put to use in the analysis of tsunami generation. There appears to be more and more cases of tsunamis which are believed to result from submarine mass movements. This is particularly important for coastal communities like in the Los Angeles area (Locat *et al.* 2001c)

## RELATED PROJECTS

Lee has developed a USGS project to investigate sediment and pollutant transport on the Los Angeles margin that uses techniques produced by STRATAFORM. Locat is investigating the behavior of a newly formed sediment layer acting as a natural cap over contaminated sediment in Canada (Saguenay Fjord). The development of this project benefited from approaches developed within STRATAFORM. Recently, a group of Canadians led by J. Locat, and H. Lee developed a new project called COSTA-Canada (CONTinental Slope STAbility) which has been linked to its European counterpart COSTA-Europe. These projects should last at least until 2003.

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## **PUBLICATIONS**

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